Electrical Measurements

Code: EPM1202

Lecture: 4 Tutorial: 2 Total: 6

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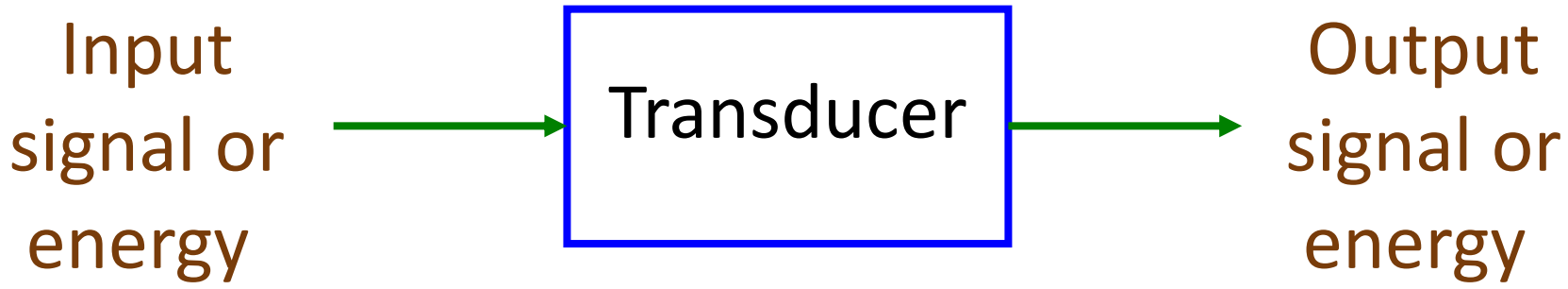
TRANSDUCERS

Definition: any electric or electronic device, which converts variations in one energy form, or generally any measurable energy into a corresponding electrical one or vice versa



TRANSDUCERS

Measurement
"input" transducers

May develop a wide range of chemical, physical, or biological effects

Output transducers
"actuators"

Designed to achieve <u>end effects</u> like opening a valve or deflection of a control element

They normally operate at high power levels

TRANSDUCERS

The term sensor is often used instead of transducer, but without involving energy transformation

Microphones convert sound waves into analogous electrical signals that can be transmitted over wires

Pressure sensor converts the physical force into an analog reading

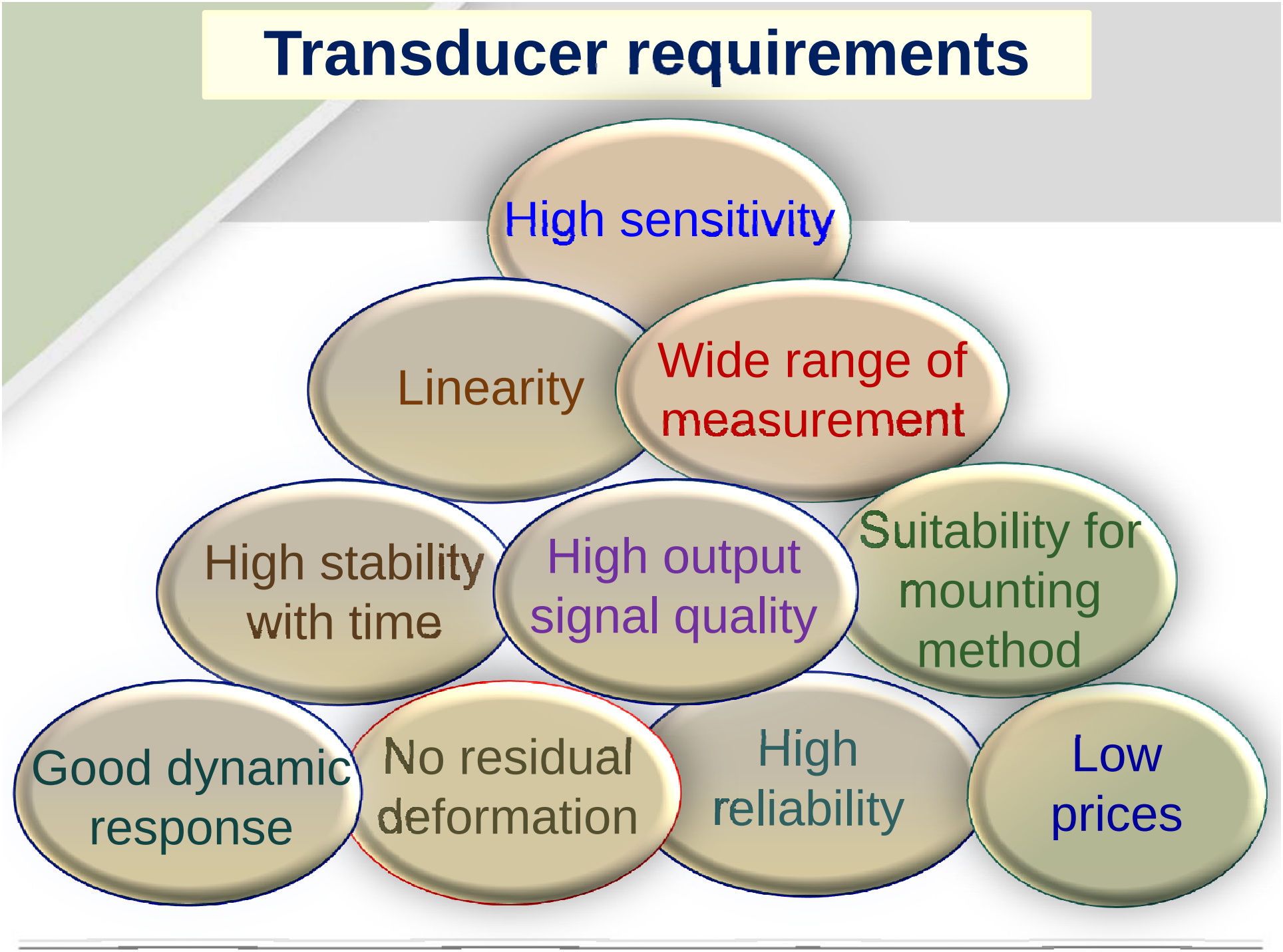
TRANSDUCERS

The scope is on transducers that have non-electrical input signals and convert them into electrical signals

It is sometimes required to use an intermediate stage in the conversion process

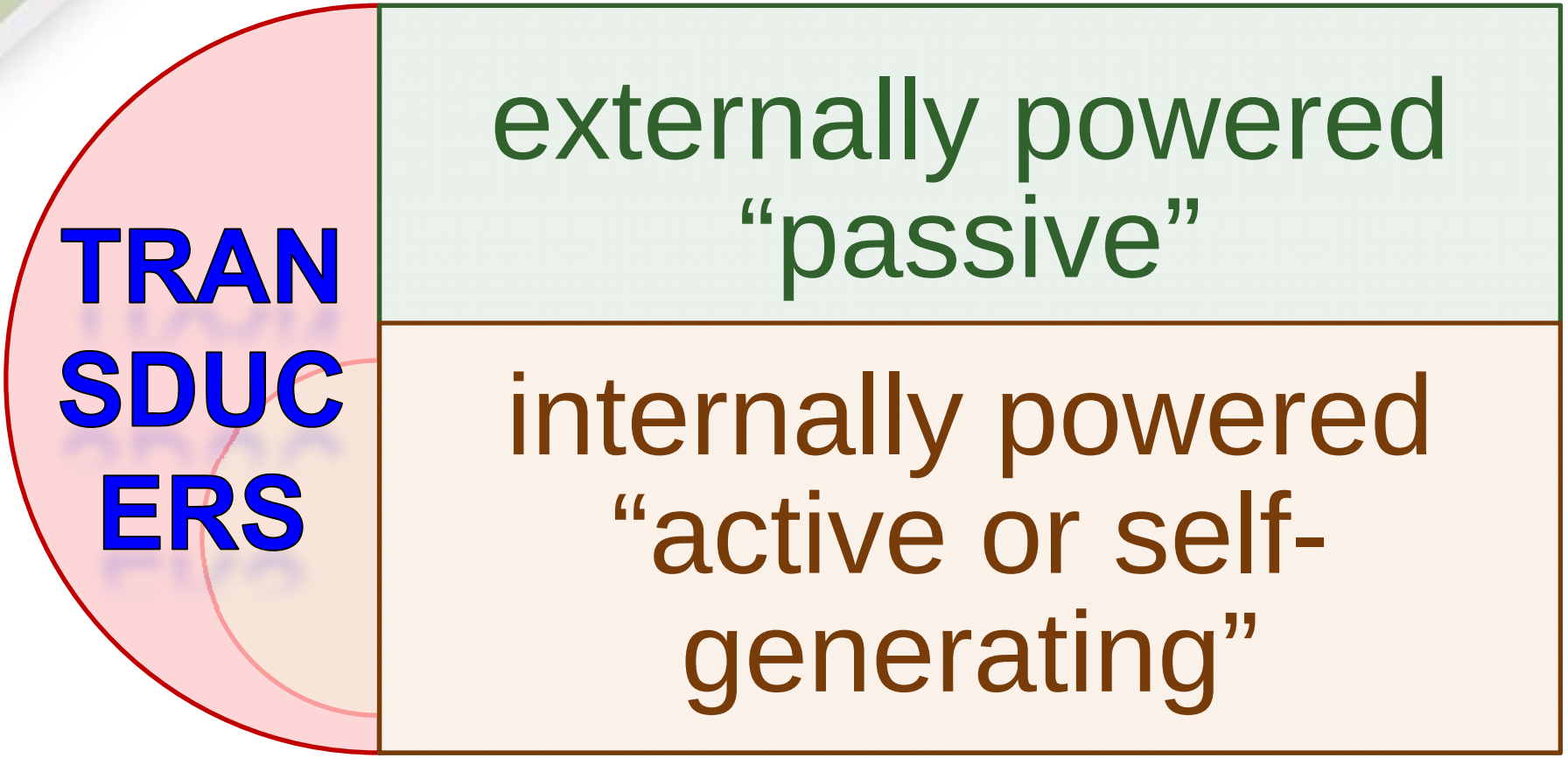
Commonly used intermediate stages can be in mechanical or magnetic forms

Transducer requirements



TRANSDUCERS

A common classification of transducers is that accounts for the type of the power source



Externally-powered transducers

Need external source to operate

Resistive Transducers

Resistive transducers are widely used due to their simplicity and cheap price

When a certain physical parameter is changed, the resistance of a device is changed

Changing the resistance can be achieved by changing the length, area or resistivity

Strain gauges depend on changing resistor dimensions, while **thermistor** and **photoconductive** transducer depend on changing the resistivity

Externally-powered transducers

Potentiometer

The potentiometer is a three-terminal resistor having a sliding contact to form an adjustable voltage divider

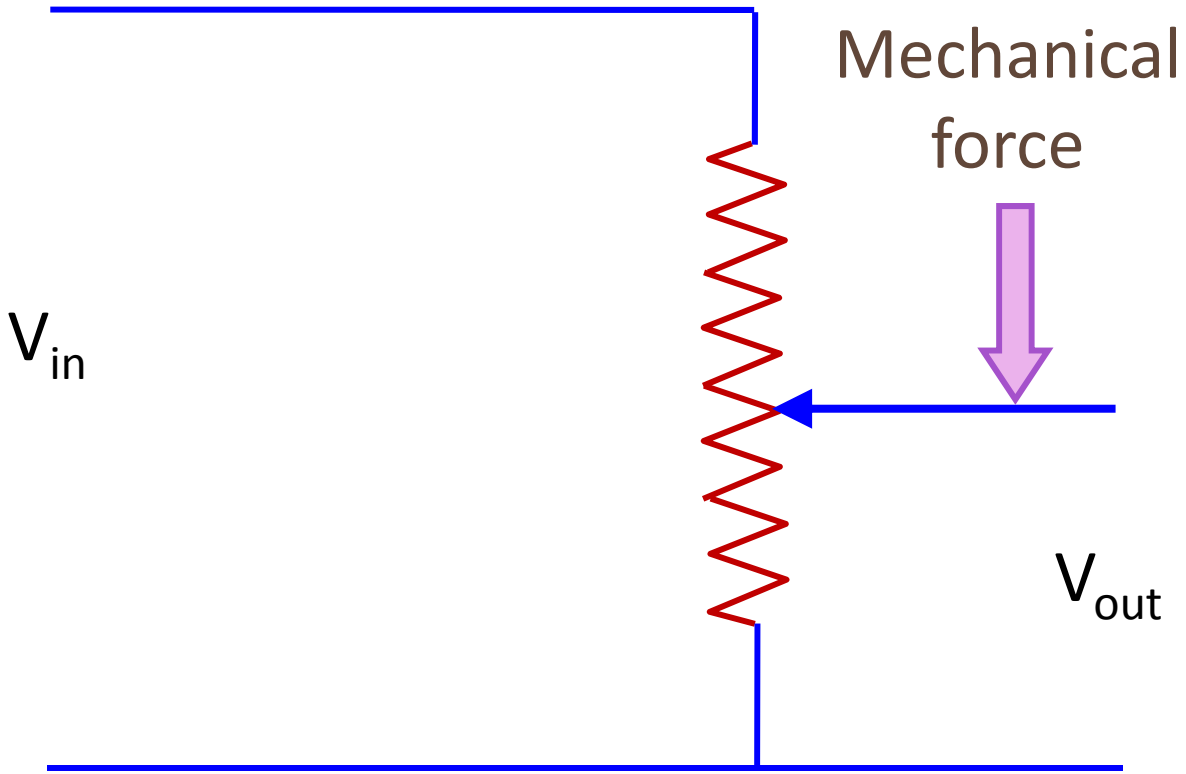
Used to control electrical devices such as volume controls on audio equipment

They can be used only for low power

The variation of the slid position can be created by a variation in the strain, pressure or temperature

Externally-powered transducers

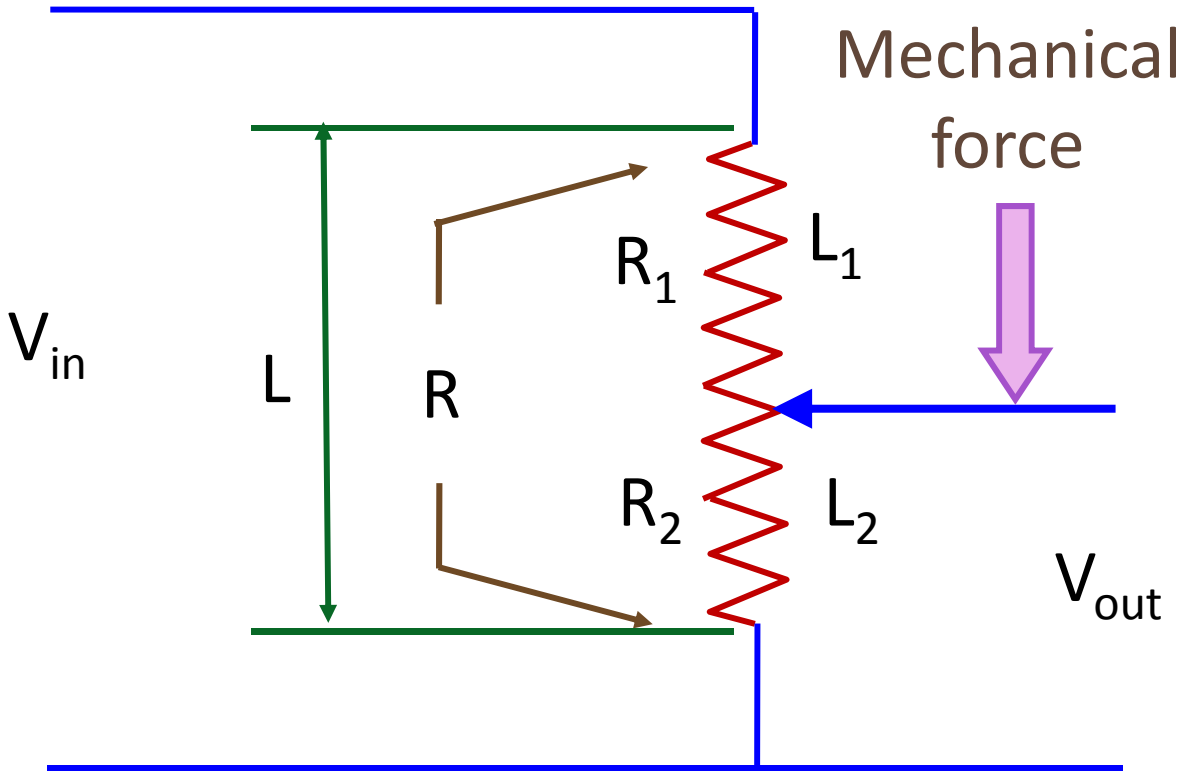
Potentiometer



Voltage divider

Externally-powered transducers

Potentiometer

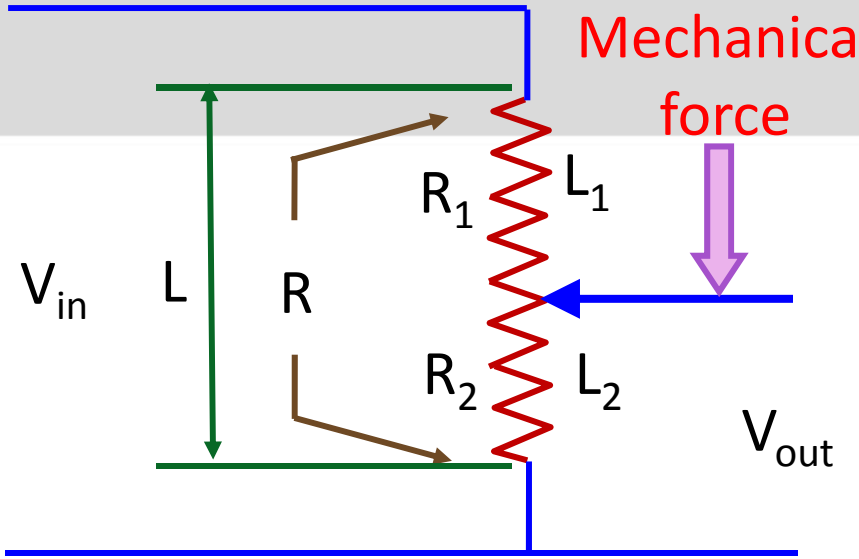


Voltage divider

Externally-powered transducers

Potentiometer

Sliding arm is connected to the moving system, whose displacement has to be measured



Changes in the position due to e.g. a change in the force causes a change in the resistance

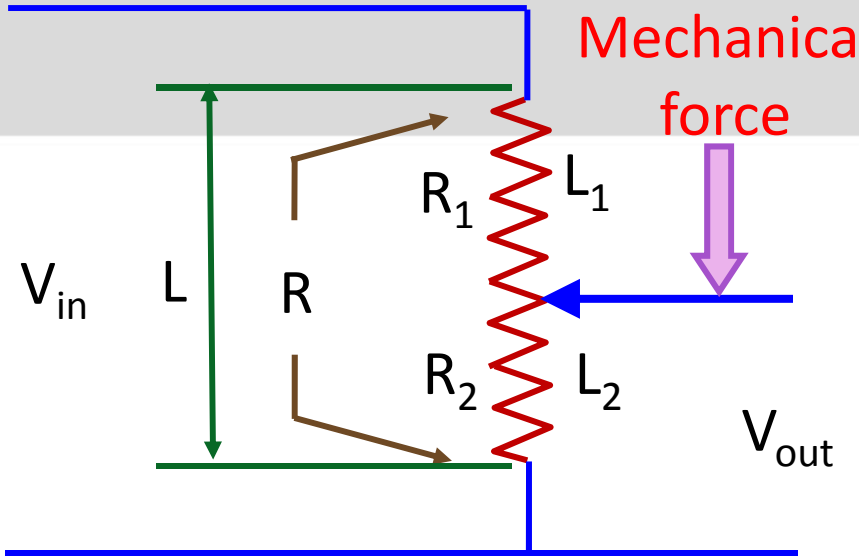
This is converted to a change in the current distribution and hence in the output voltage

The system is calibrated to have a voltage that is proportional to the change in the displacement

Externally-powered transducers

Potentiometer

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$



$R_1 + R_2 = R_T$

$R_1 = \rho L_1 / a$

$R_2 = \rho L_2 / a$

$R_T = \rho L / a$

$$V_{out} = \frac{\rho L_2 / a}{\rho L / a} V_{in} = \frac{L_2}{L} V_{in}$$

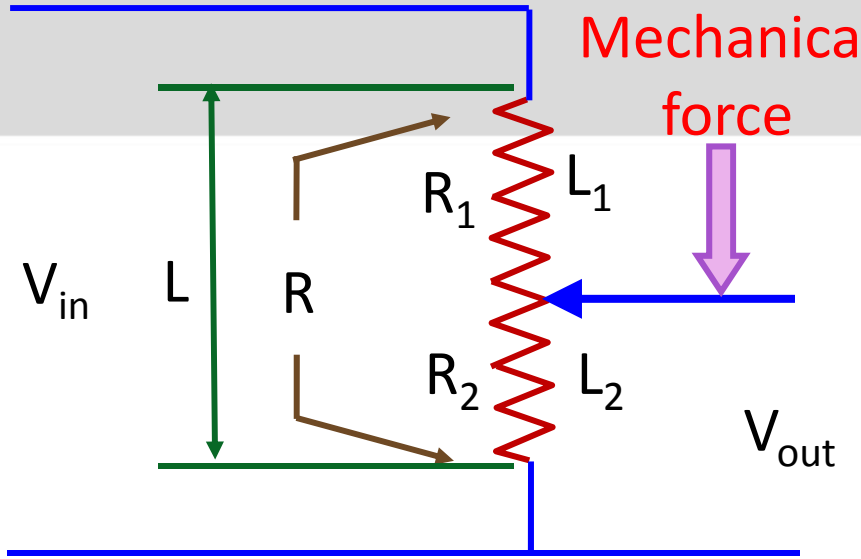
$$V_{out} \propto L_2$$

Externally-powered transducers

Potentiometer

The circuit is used also to indicate the velocity

Differentiating the output voltage gives a signal representing the velocity



A second differentiation of the output voltage gives a signal proportional to the acceleration

$$V_{out} \propto L_2$$

$$\frac{dV_{out}}{dt} \propto \frac{dL_2}{dt}$$

$$Velocity \propto \frac{dL_2}{dt}$$

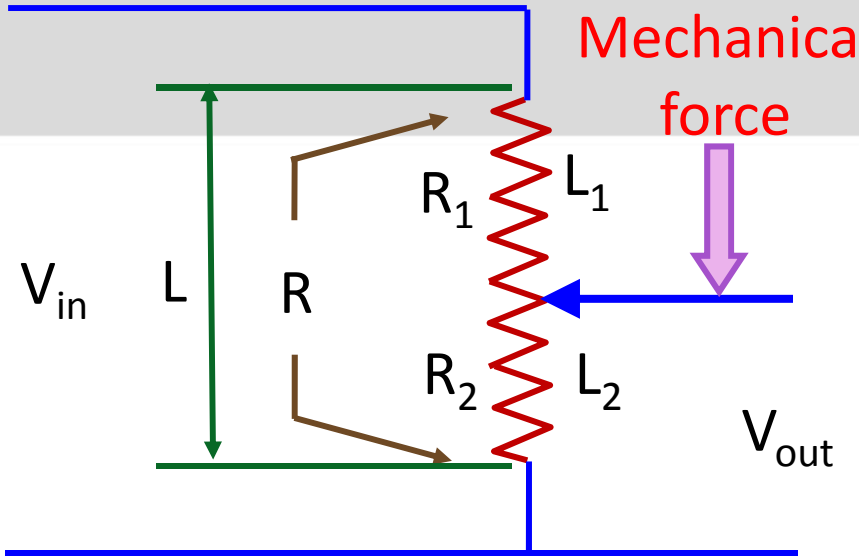
Externally-powered transducers

Potentiometer

$$Velocity \propto \frac{dV_{out}}{dt}$$

$$\frac{d^2V_{out}}{dt^2} \propto \frac{d^2L_2}{dt^2}$$

$$Acceleration \propto \frac{d^2L_2}{dt^2}$$



$$Acceleration \propto \frac{d^2V_{out}}{dt^2}$$

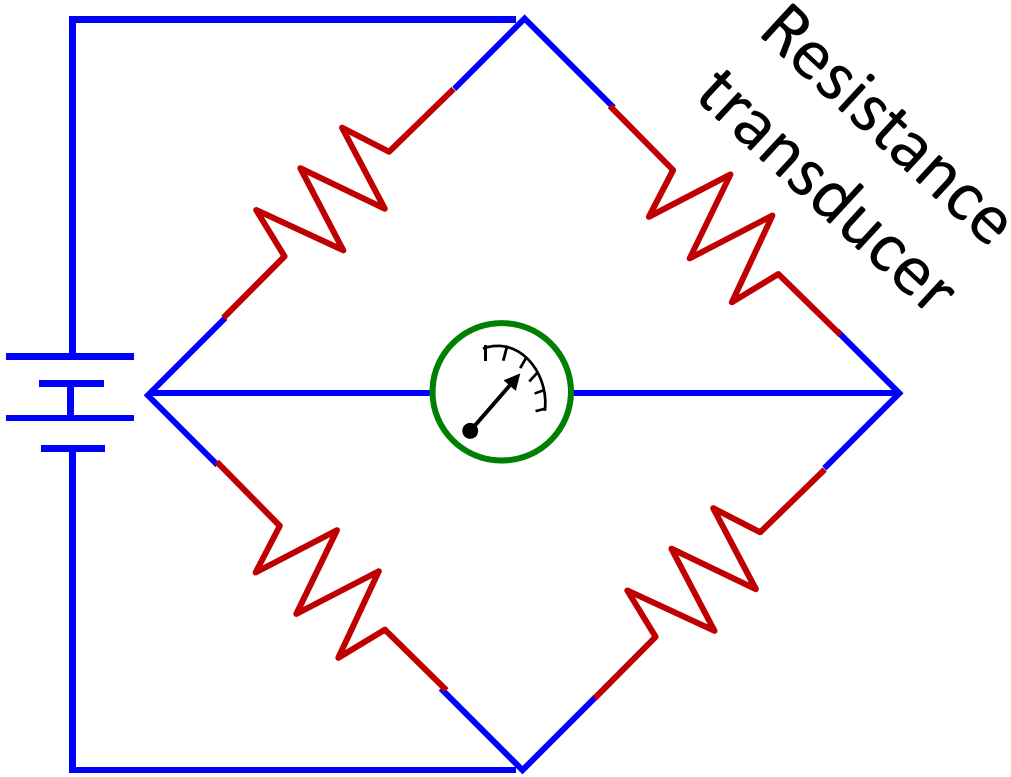
Externally-powered transducers

Potentiometer using Wheatstone bridge

The measured resistance is used as one arm in the bridge

The measured value is proportional to the resistance value

The value of the resistance can be calculated and hence, the measured value can be calculated



Externally-powered transducers

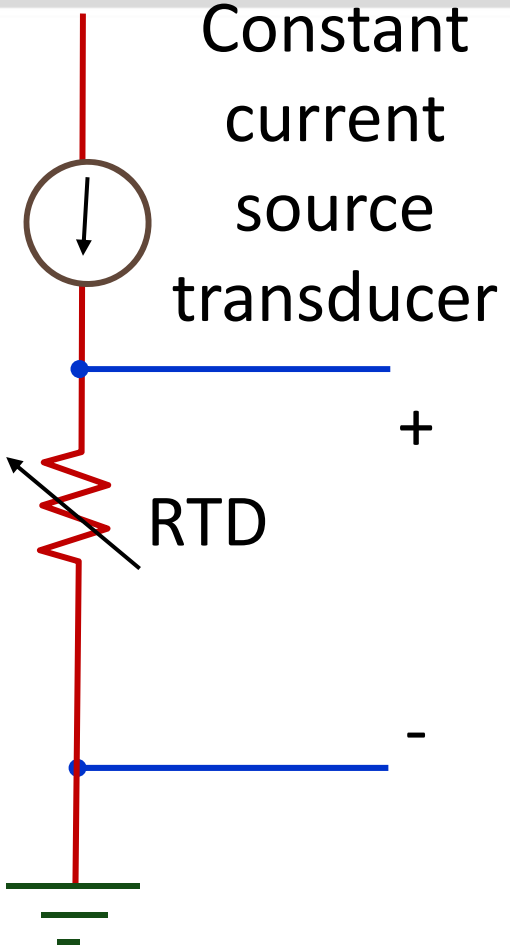
Resistance temperature detector

The RTD is one of the most accurate temperature sensors

It provides good stability and repeatability

Immune to electrical noise

Well suited for temperature measurement especially around motors, generators and other high voltage equipment



Externally-powered transducers

Resistance temperature detector

The temperature variation causes a change in the resistance value

$$R_T = R_o\left(1+\alpha\left(T - T_o\right)\right)$$

R_T is the resistance at any temperature “T”

R_o is the resistance at the ambient temperature “T_o”

α is temperature coefficient

The resistance has a linear relation with temperature

Externally-powered transducers

Thermistor

Based on semiconductors and act with the same idea of the RTD

The concentration of charge carriers changes very rapidly with a change in temperature leading to a rapid decrease in resistivity as temperature increases

They have negative temperature coefficient "α"

Have high sensitivity and represent excellent tool for highly sensitive temperature measurements

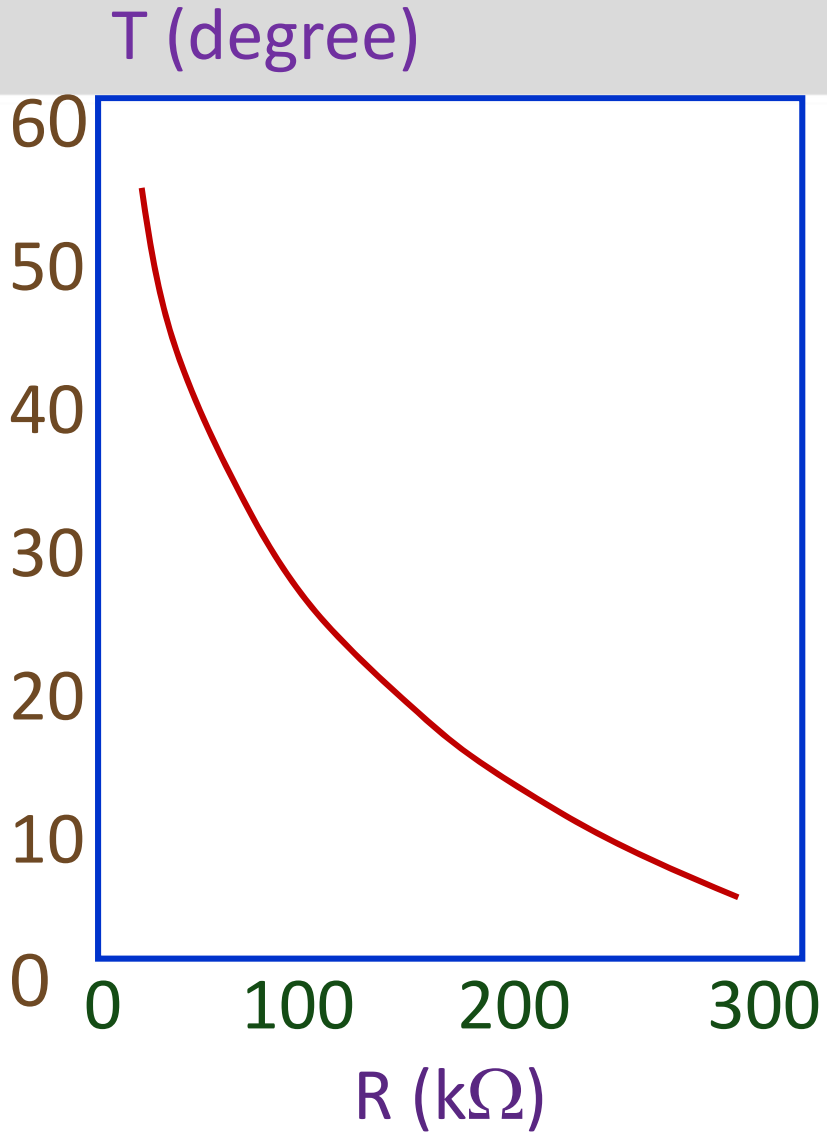
Externally-powered transducers

Thermistor

$$R_{T1} = R_{T2}\, e^{\left(\beta\left(\frac{1}{T_2}-\frac{1}{T_1}\right)\right)}$$

R_{T1} and R_{T2} are the resistances of the thermistor at absolute temperature "T_1" and "T_2" in Kelvin

β is a constant for the thermistor material (between 3500 and 4500)



Externally-powered transducers

Strain gauge

A sensor whose resistance varies with applied force

It converts force, pressure, tension, weight, etc., into a change in electrical resistance

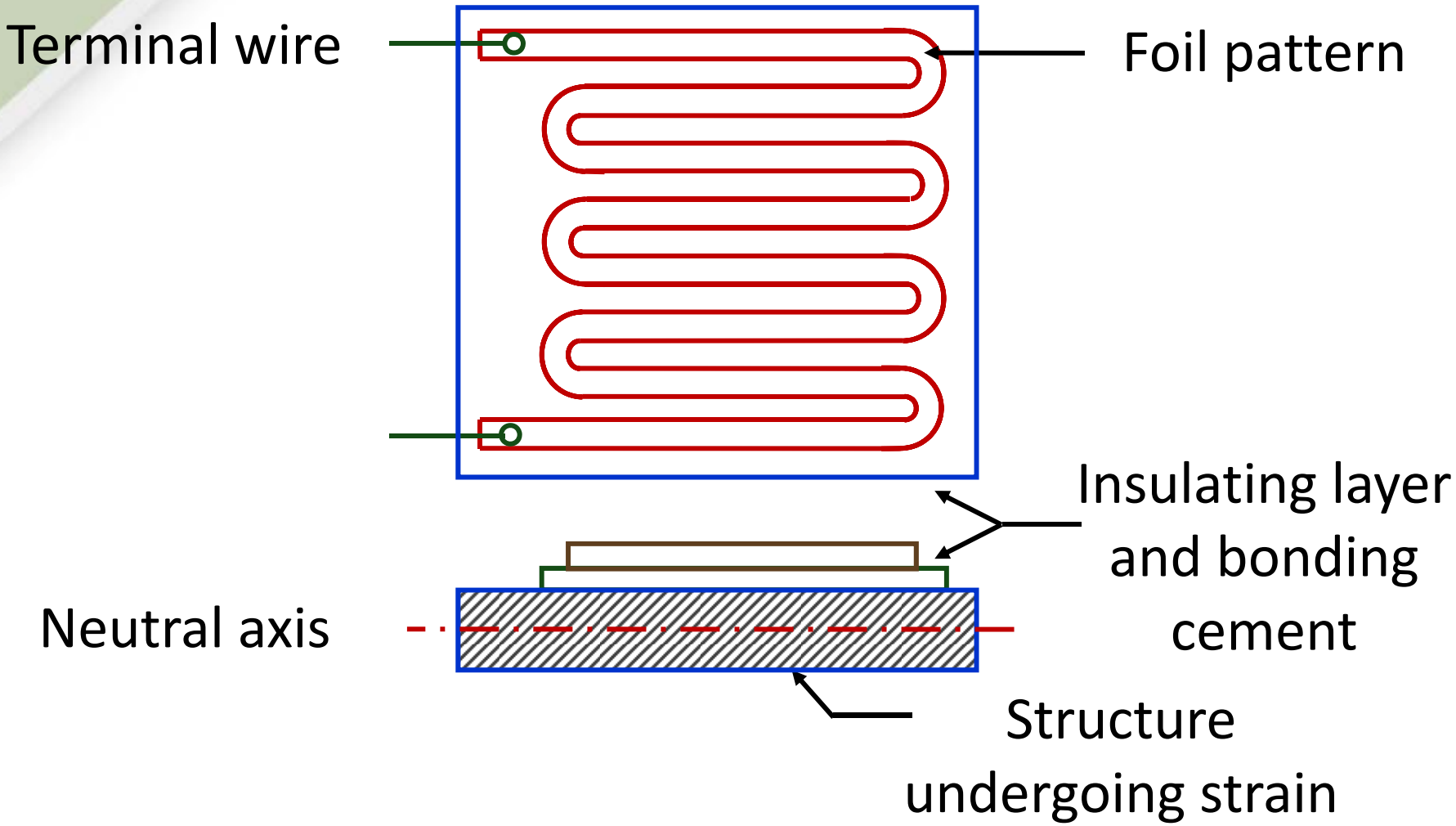
When a resistor of fine wire is distorted, its resistance changes as a result of dimensional change

Applying external forces to a stationary object results in stress and strain

The value of the resistance is related to the strain

Externally-powered transducers

Strain gauge



Externally-powered transducers

Strain gauge

The resistance change is usually a very small fraction of the total resistance

A very sensitive resistance measurement technique has to be applied

A Wheatstone bridge configuration can be used with a temperature controlled strain gauge in order to maximize the sensitivity of the measurement

Externally-powered transducers

Strain gauge

$\frac{\Delta L}{L}$: the normalized change in the wire length

$\frac{\Delta d}{d}$: the normalized change in the wire diameter

$\frac{\Delta a}{a}$: the normalized change in the wire cross section area

$\frac{\Delta R}{R}$: the normalized change in the wire resistance

Externally-powered transducers

Strain gauge

$$R = \frac{\rho L}{a}$$

$$a = \frac{\pi}{4} d^2$$

$$\frac{\Delta R}{R} = \frac{\Delta L}{L}(1 + 2\gamma)$$

"γ" is the Poisson's ratio $\gamma = -\frac{\partial d / d}{\partial L / L}$

"K" is the Gauge factor, the ratio between the change in the resistance to the change in the wire length:

$$K = \frac{\Delta R / R}{\Delta L / L}$$

$K = 1 + 2\gamma$

Externally-powered transducers

Strain gauge

For acceptable operation of strain gauge transducers, they have to provide the following characteristics:

- A high resistance
- A Low temperature coefficient
- A suitable frequency response
- A high gauge factor
- A linear resistance-strain relation

Externally-powered transducers

Strain gauge

Example: The gauge factor of a strain gauge transducer is 2.0. If the normal resistance of the strain gauge is 100Ω, find the strain-gauge resistance when subjected to a strain of $2*10^{-3}$

Solution:

$$K = \frac{\Delta R / R}{\Delta L / L} \Rightarrow \Delta R = K\ \mathrm{R}\left(\Delta L / L\right)$$

$\Delta R = 2 * 100 * 2*10^{-3} = 0.4\ \Omega$

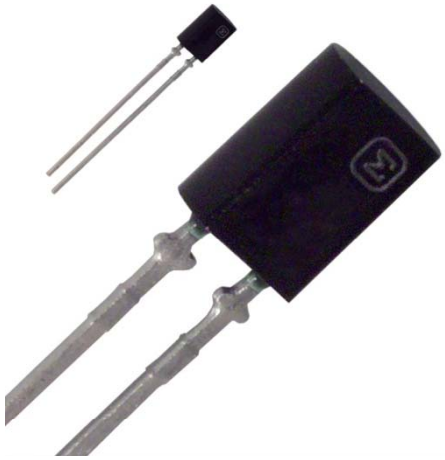
$R_{new} = R + \Delta R = 100 + 0.4 = 100.4\ \Omega$

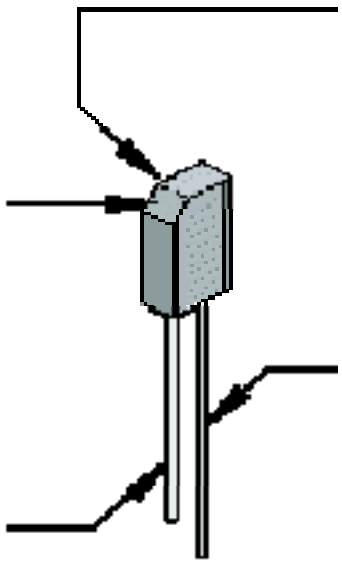
Externally-powered transducers

Photodiode

Light causes creation of electron-hole pairs in the junction with the current proportional to light intensity

They can be damaged by high light levels

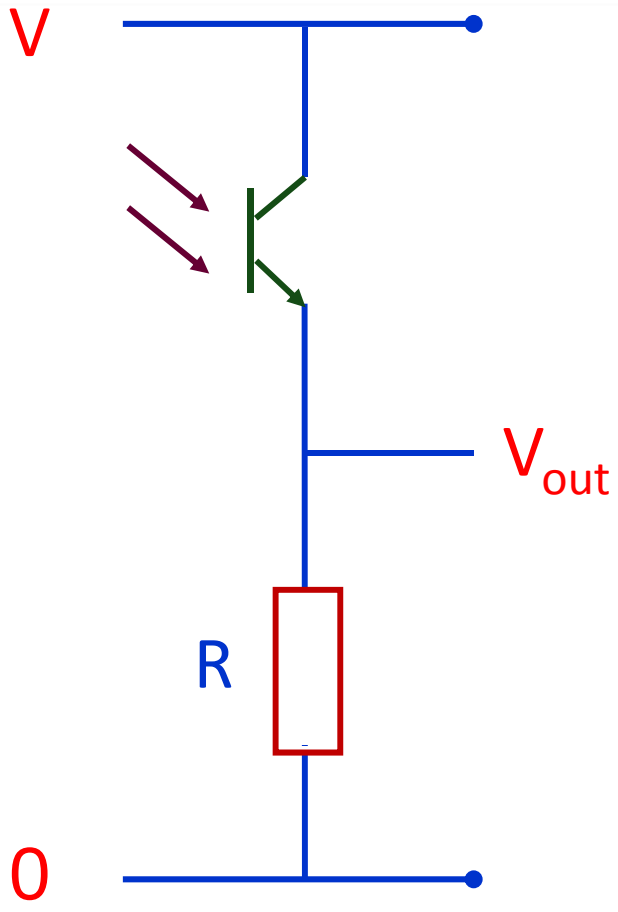




Externally-powered transducers

Photodiode

Output current is converted to a voltage using special arrangements



Self generating transducers

“Active or Energy Conversion Transducers”

They require no external power source since they derive their energy from the measured quantity

To obtain linear relations

The circuit is short-circuited and the output current is measured

The circuit is opened and the output voltage is measured

Self generating transducers

Photovoltaic Cells

The device directly converts incident light into electrical energy

It is a reversal form of LED

When light falls on a junction between dissimilar materials, charge carriers are moved and hence a potential difference is created between the materials

The potential difference is a function of the incident flux

Self generating transducers

Thermocouple

When two different metals are connected together in a closed loop and the junction is heated, current flows in the loop

If the loop is opened, a potential difference is produced across the two terminals

The open circuit voltage is termed "Seebeck voltage"

Thermocouples convert thermal energy into electrical energy

Self generating transducers

Thermocouple

The thermocouple works by creating a voltage difference between two wires that is proportional to the temperature at the junction

The voltage generated between the two ends “Seebeck voltage ” is a function of the temperature difference between the two junctions “the heated junction and the cooled terminal”

Self generating transducers

Thermocouple

$$E = k_1(T_h - T_C) + k_2(T_h^2 - T_C^2)$$

E = Seebeck voltage

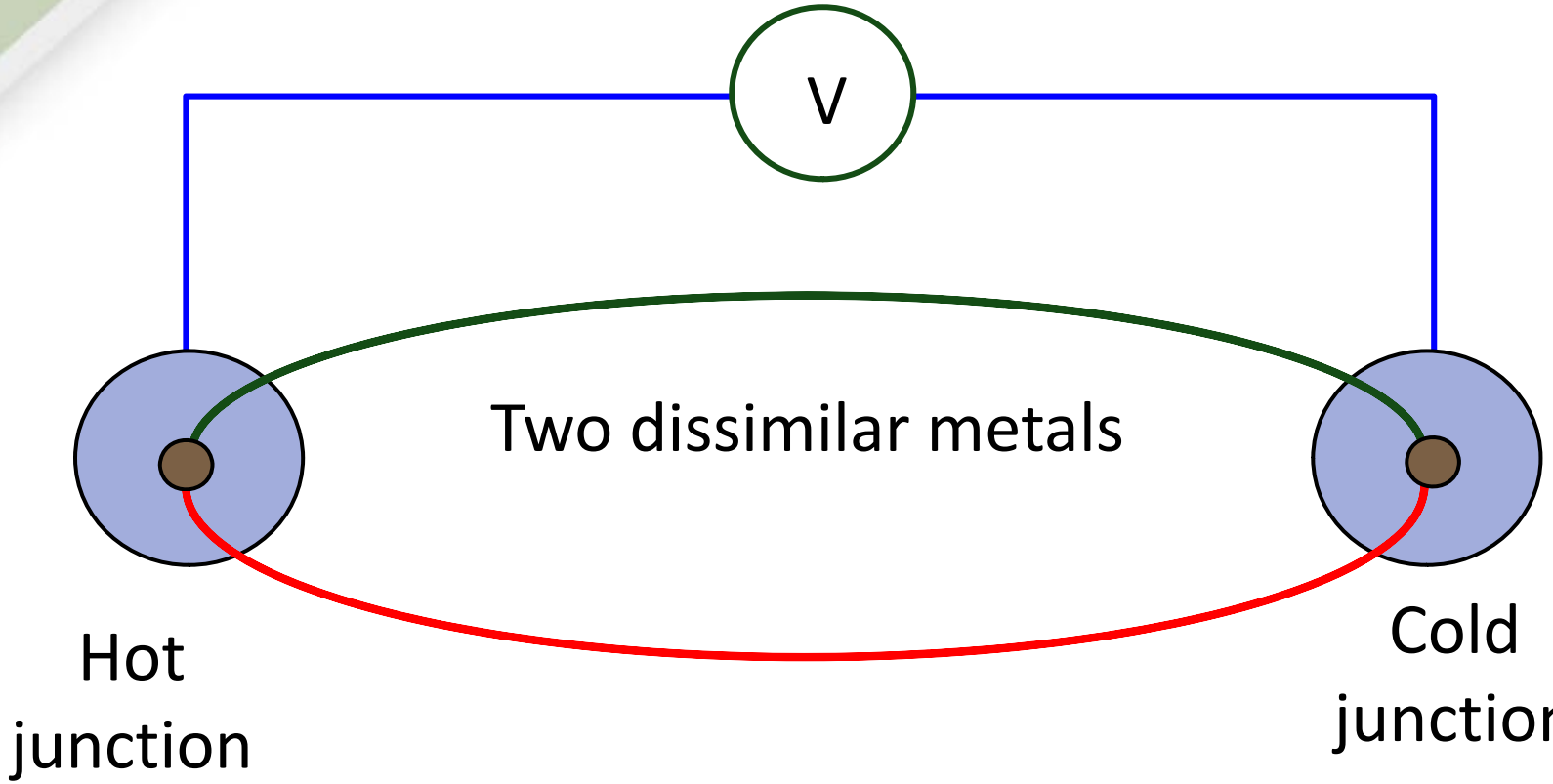
T_h = Hot-junction temperature

T_C = Cold-junction temperature

k_1 and k_2 are constants for the thermocouple materials

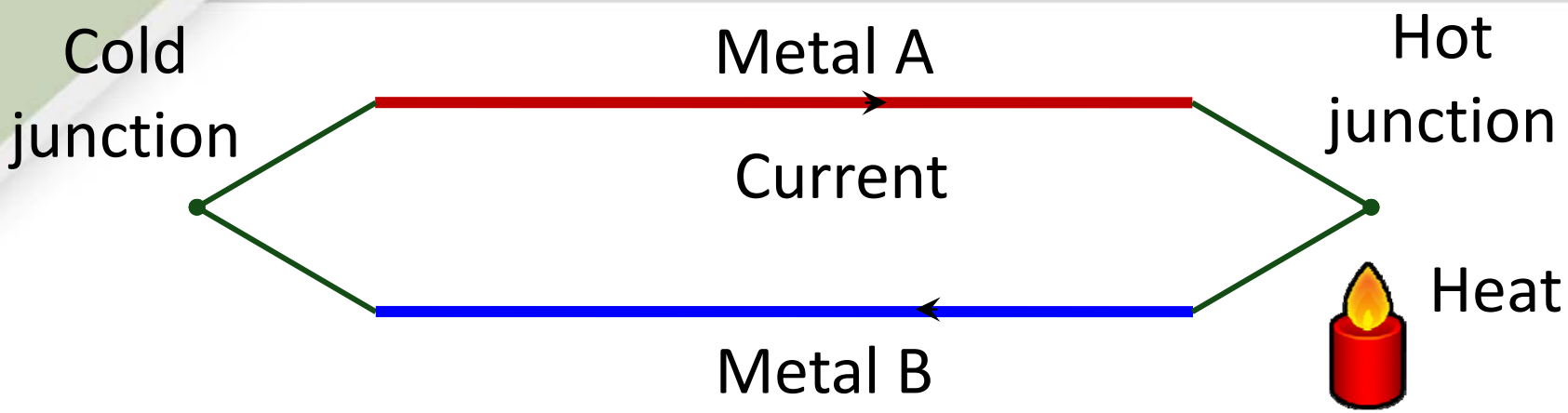
Self generating transducers

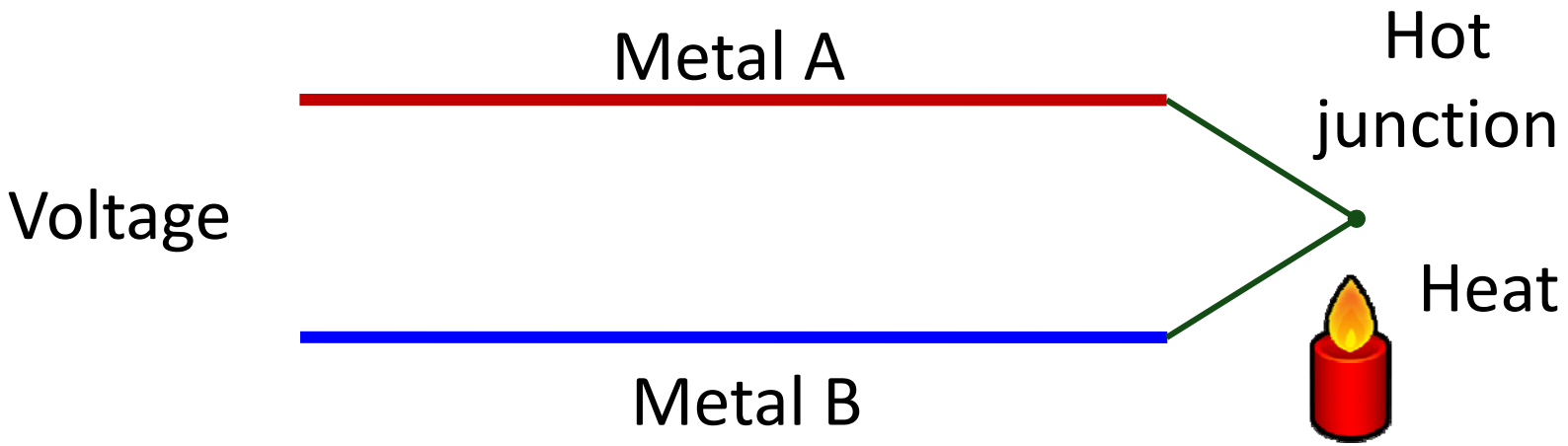
Thermocouple



Self generating transducers

Thermocouple





Self generating transducers

Piezoelectric Transducers

When some special crystals with non-uniform charge distribution is subjected to mechanical pressure or vibration, a change in its dimensions takes place

As a result, a polarization is produced and a potential difference between the material terminals appears

In addition, the reverse process is also possible

When an alternating field is applied to a transducer, the material will vibrate back and forth producing an ultrasonic frequency “ultrasonic transducers”

Piezoelectric transducers are also used as pressure meters and in speakers to produce sound waves

Self generating transducers

Variable Inductance Type Transducer

The variation of inductance can be made by the variation of self inductance, mutual inductance and the eddy current production

The output of the transducer can be measured directly in the form of inductance variation or in the form of voltage variation

When working on principle of changing self inductance, the self inductance of a coil is given as

$$L = \frac{N^2}{R}$$

Self generating transducers

Variable Inductance Type Transducer

Change of Self Inductance

$$L = \frac{N^2}{R}$$

$$R = \frac{\ell}{\mu A}$$

$$L = \frac{N^2 \mu A}{\ell} = N^2 \mu \frac{A}{\ell}$$

"A" is the of cross section area of the magnetic path

"ℓ " is the length of the magnetic path

"μ" is the permeability

Self generating transducers

Variable Inductance Type Transducer

Change of mutual Inductance

$$M = k\sqrt{L_1 L_2}$$

Producing eddy currents:

If a conducting plate is placed near a coil carrying alternating current, eddy currents are produced in the conducting plate

Self generating transducers

Capacitive Transducer

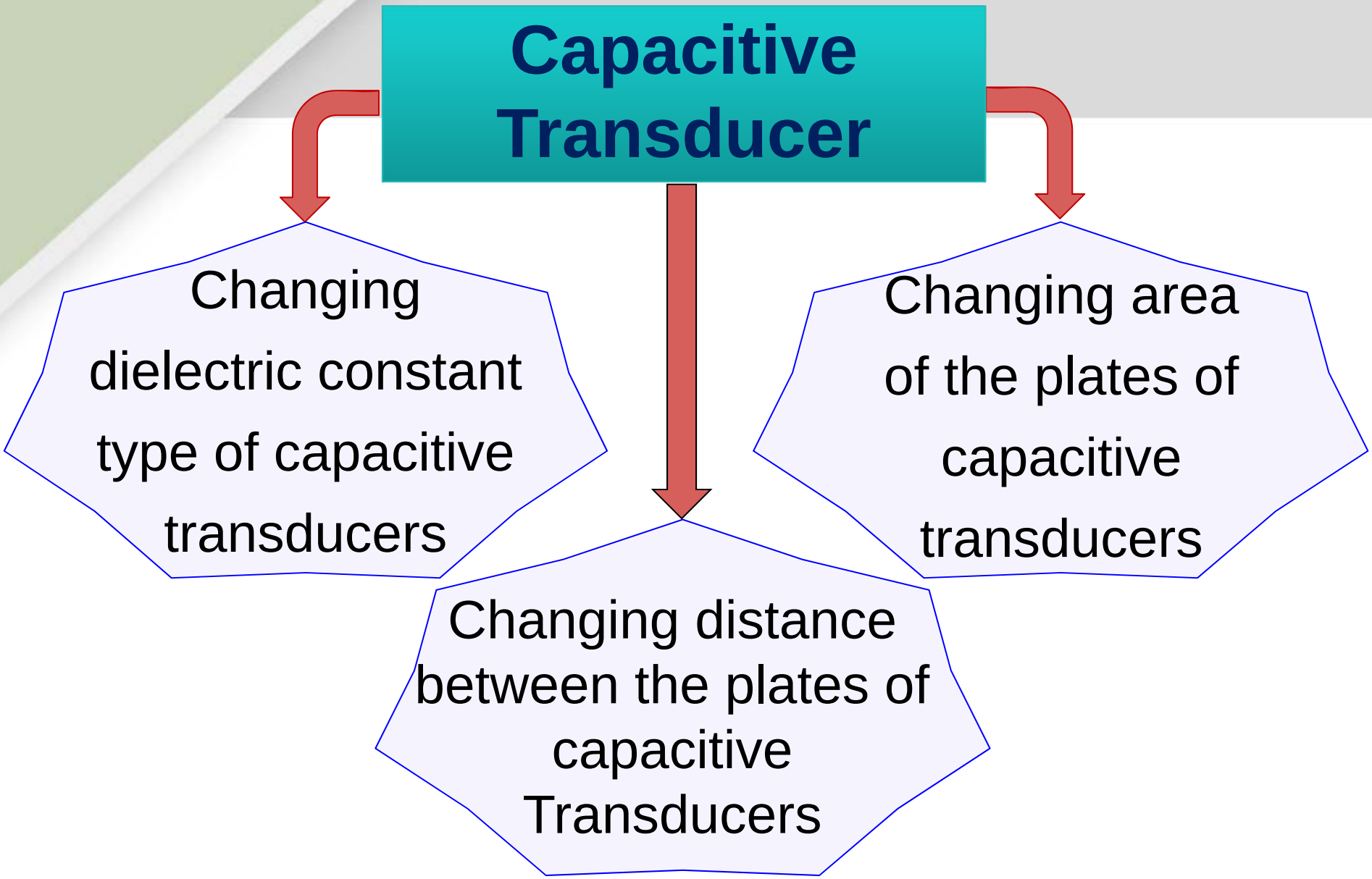
$$C = \frac{\varepsilon A}{d} = \frac{\varepsilon_o \varepsilon_r A}{d}$$

One plate of the capacitor is movable and hence, the distance between the two plates is varied

The variation of the distance between the plates causes a capacitance variation

$$\Delta C = \frac{\varepsilon_o \varepsilon_r A}{\Delta d}$$

Self generating transducers



Self generating transducers

Changing dielectric constant:

The variation of the measured quantity changes the value of the dielectric constant

Used to measure levels of liquids in container, resulting in a change in the dielectric constant

This principle can also be used for measurement of humidity and moisture content of the air

Changing area of the plates:

Used for measurement of the torque on the shaft

Changing distance between the plates

Used to measure pressure, velocity, acceleration etc